



## **Scalability of Robotic Controllers: An Evaluation of Controller Options—Experiment II**

**by Rodger A. Pettitt, Elizabeth S. Redden, Nicholas Fung,  
Christian B. Carstens, and David Baran**

**ARL-TR-5776**

**September 2011**

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# **Army Research Laboratory**

Aberdeen Proving Ground, MD 21005

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**Human Research and Engineering Directorate, ARL**

# REPORT DOCUMENTATION PAGE

*Form Approved*  
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1. REPORT DATE (DD-MM-YYYY) September 2011		2. REPORT TYPE		3. DATES COVERED (From - To) 2-13 August 2010	
4. TITLE AND SUBTITLE Scalability of Robotic Controllers: An Evaluation of Controller Options-Experiment II				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Rodger A. Pettitt, Elizabeth S. Redden, Nicholas Fung, Christian B. Carstens, and David Baran				5d. PROJECT NUMBER 622716H7099	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: RDRL-HRM-DW Aberdeen Proving Ground, MD 21005				8. PERFORMING ORGANIZATION REPORT NUMBER  ARL-TR-5776	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT This experiment was designed to investigate options for scaling robotic controllers for use by dismounted Soldiers. A touch-screen controller has the potential to be smaller and lighter than other controller devices because the display and controls are combined in one space. Soldiers' performance using an Android touch-screen controller was compared with their performance using a baseline Xbox 360 joystick controller. Thirty Soldiers from the Officers' Candidate School served as participants. Each Soldier completed outdoor and indoor driving courses using both controller types in counter-balanced order. Course completion times were significantly faster with the Xbox controller compared to the Android controller. In addition, there were significantly fewer driving errors and off-course errors with the Xbox controller. Total workload ratings were significantly lower for the Xbox than for the Android. Although the touch-screen controller can be used to teleoperate a robot, it has several shortcomings. The primary benefit of the touch-screen controller is its small size and light weight. However, the Android had substantial costs in terms of speed, accuracy, and workload associated with teleoperation. Touch-screen performance might be improved by incorporating haptic or auditory feedback and by recalibrating some functions such as modifying top speed, turning rate, and acceleration.					
15. SUBJECT TERMS Android, touch screen, controller, robotic					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (Include area code)
Unclassified	Unclassified	Unclassified	UU	60	Rodger A. Pettitt (706) 545-9142

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# 1. Introduction

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## 1.1 Background

Typically, when interface designers talk about scalable interfaces, they are referring to a design that ensures development considers the requirement to change over time. For this experiment, we are concentrating on a more narrow definition of scalability. We are concerned with the ability to scale down interfaces in terms of size and weight and the effect of this scaling on the cognitive load of robotic operators. Soldiers operate in a large range of environments, from the relatively stable and spacious environment of a tactical operations center (TOC), to the cramped and constantly moving environment of a vehicle, to the rugged and challenging environment of the dismounted Soldier. All of these environments impose different demands on the size and configuration of the robotic interface. For example, a dismounted Soldier cannot carry the relatively large controller that would be appropriate for use in a TOC. This type of interface scalability is very important because it ensures that training transfer is easily achieved across environments and that interfaces can be tailored to specific environments and conditions. The operational definition of scalability used in this experiment is as follows: “The transmission of critical information to the Soldier tailored for each level of combat to ensure mission success while maximizing survivability by minimizing equipment requirements; minimizing multitasking workload, maximizing situation understanding, and maximizing aerial and ground robotic mission effectiveness” (Merlo, 2006). A similar definition is “The tailored reception and transmission of mission essential information at the appropriate level for the Soldier, to ensure mission success while maximizing the survivability and lethality through the synergistic interaction of equipment requirements, appropriate cognitive workload, situation awareness and understanding for oneself and others connectivity of distributed intelligent agents” (Barnes, 2006).

The key to ensuring that a system is scalable is to consider not only the range of devices that Soldiers will use, but also their context of use. A familiar example of a context-sensitive application is e-mail access. Typically, users have used their desktop computers to access email but more and more frequently, they are now using personal digital assistants (PDAs) and cell phones to do the same job when they are outside of their offices. Robots can be teleoperated through a wide variety of control media, ranging from hand-held devices such as PDA systems (Fong et al., 2004; Quigley et al., 2004) and cellular phones (Sekmen et al., 2003) to multiple panel displays with control devices such as joysticks, wheels, and pedals (Kamsickas, 2003). The input devices for smaller interfaces are quite different from those found in offices, vehicles, or other environments in which the operator is not responsible for carrying the device and can potentially impact the complexity of operation, the speed of operation, and the accuracy of input. Designing for the “optimum” input device size makes sense as long as the interface environment

and operating conditions can be specified in advance. However, if an input device is designed so that it is only practical in one environment, it may be completely unusable in another and for future tasks or unexpected conditions. Other factors of scalability that will be addressed in subsequent experiments include structure or organization of the content of an interface (a desktop computer may use a presentation that is optimized when using a high-resolution monitor, while a user of a PDA might view the information in a text-only presentation) and information requirements of users in different environments.

Space to incorporate controls on small-size controllers is very limited. Miniaturizing individual input controls as controller sizes get smaller is not always an option, as Soldiers have to be able to operate them individually without accidental activation of adjacent controls while wearing gloves. Thus, the designer of controllers must be creative during function mapping; this often drives them to using multifunction controls. The problems with multifunction controls are that they can increase control activation time and increase the cognitive complexity of the controller. Other creative approaches to controller size reduction that have been developed in the past are sketch interfaces (Skubic et al., 2003; Setalaphruk et al., 2005), voice recognition and synthesis systems (Chen et al., 2006), and hands-free systems (Veronka and Nestor, 2001). However, these novel controls often present problems of their own and are still being refined. In the meantime, there is an immediate requirement for controls for dismounted Soldiers to teleoperate robots. There is also not a great deal of empirical data on the impact of decreasing the size of controllers for dismounted operations.

This experiment was the second in a series of experiments designed to investigate current and future options for scaling robotic controllers specifically for use by dismounted Soldiers. In the first experiment, controller type, workload, and usability were evaluated (Pettitt et al., 2008). The controllers used were a multifunction control mounted on a weapon, a gaming controller with reduced control sizes, and the larger robot legacy controller. Findings indicated that the multifunctional controller was more difficult to learn how to use than the controller with the reduced control sizes because switching between functions was time consuming and confusing. Also, many simultaneous functions could not be accomplished with the multifunctional controller. In this experiment, we chose the gaming controller used in the previous experiment as the baseline condition. We compared the gaming controller to a touch-screen controller that allows the display and control functions to be combined in one space. Both controllers were programmed to provide the same functions. Pretest experimentation was performed to ensure that the functional mapping of each of the controller was as effective as possible. The tradeoffs between interface size and weight with these controllers vs. input speed, accuracy, training time, and cognitive load were examined.

## **1.2 Objective**

The goal of this research was to investigate the ability of Soldiers to use a touch-screen robotic controller. Soldiers' performance using an Android touch-screen controller was compared with their performance using a baseline joystick controller.

## **1.3 Overview of Experiment**

This study was a cooperative research effort between the U.S. Army Research Laboratory (ARL)/Human Research and Engineering Directorate (HRED) and ARL's Computational and Information Sciences Directorate (CISD). It was an investigation of the effect of controller scalability on robotic control and took place at Fort Benning, GA. Thirty Soldiers from the Officer Candidate School (OCS) participated in the study. After training on the operation of the PackBot Robot system, each Soldier completed the indoor and outdoor courses, once with each controller type. The sequence of controller type was counterbalanced to control for order effects. Controller usability was evaluated based on objective performance data, data collector observations, and Soldier questionnaires.

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## **2. Method**

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### **2.1 Participants**

Thirty Soldiers from the Ft. Benning OCS participated in the assessment. The OCS participants included Soldiers with prior enlisted service with a variety of backgrounds and experience levels as well as those just coming into the Army from college.

#### **2.2.1 Pretest Orientation**

The Soldiers were given an orientation on the purpose of the study and what their participation would involve. They were briefed on the objectives, procedures, and the robotic system. They were also told how the results would be used and the benefits the military could expect from this investigation. Any questions the subjects had regarding the study were answered.

### **2.2 Apparatus and Instruments**

#### **2.2.1 PackBot Robot**

The PackBot Explorer Robot is a variant of the PackBot which has been fielded to Operation Iraqi Freedom and Operation Enduring Freedom since 2003. The platform is a man-portable small unmanned ground vehicle which can be used for reconnaissance tasks including entering and securing areas that are either inaccessible or too dangerous for humans (see figure 1). The PackBot Explorer payload has a rotating pan and tilt head equipped with multiple cameras, which was kept in a fixed position for this experiment. The robot was also equipped with a

Hokuyo laser detection and ranging (LADAR) sensor used to provide obstacle detection and avoidance capabilities (O'Brien et al., 2010). These capabilities were available to the operator during the indoor trials of the experiment.



Figure 1. iRobot PackBot explorer robot.

### 2.2.2 Robotic Vehicle Controllers

Two operator control units (OCUs) were used during this experiment. The first was an Itronix tablet that was carried in the Soldiers' backpacks and connected to a Microsoft Xbox\* 360 game controller (see figure 2) and a handheld Android phone with a touch-screen interface (see figure 3). The second configuration was just the Android phone. The Android video display (3.17 inches in diagonal with  $320 \times 480$  pixel resolution) was used to view the video feed from the Packbot when both types of configurations were used. This was done so that the size of the video display was held constant and would not impact operator performance with either of the two controller types being evaluated.



Figure 2. Xbox 360 controller.

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\* Xbox is a trademark of Microsoft Corporation.

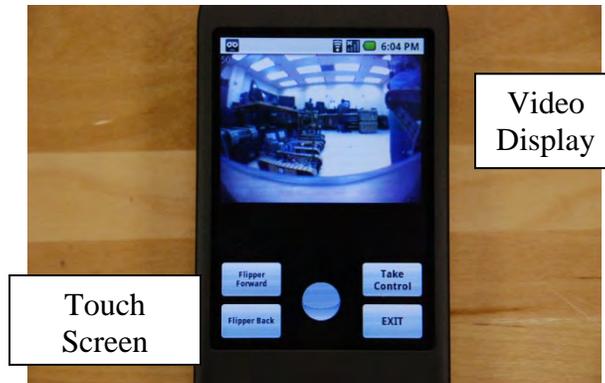


Figure 3. Android phone.

Under the first configuration, the Xbox 360 controller was used as the source of input from the user, and the Android phone was used as the video output device. The anticipated primary advantage of this configuration was that the Xbox controller is optimized for user input. Video games have become ubiquitous in modern society; as such, Microsoft and other game companies have advanced controller design over the course of many years of research and investment. In addition, many Soldiers were expected to have some experience with the controller from personal use. The anticipated primary disadvantages of this configuration were the weight and size. This configuration requires the Itronix tablet computer that the Soldier carried in a backpack. In addition, the Xbox controller requires two hands to use and is an additional piece of equipment that must be carried.

The second OCU configuration used only the Android phone for both control and video. The control portion of the Android interface involves four buttons and a virtual joystick controlled through the touch interface of the phone. The virtual joystick is operated by touch input in a bounded square immediately surrounding the center joystick dot. Touching within the upper half of the square sends a “forward” command to the robot. Similarly, touching on the left half of the square will send a “turn left” command to the robot and likewise for “turn right” and “back up.” The user interface allows analog control of the robot. The further from the center the touch input, the faster the robot will move in that direction. The primary anticipated advantage of this controller is the small packaging. Using the Android OCU configuration allows one-hand control in addition to the elimination of the backpack, tablet computer, and controller. Anticipated disadvantages of this configuration included a higher demand in user precision. The virtual joystick has a smaller degree of movement and does not have the physical feedback given by the thumbstick of the Xbox controller.

### 2.2.3 Outdoor Robotic Driving Course

The robotic course (figure 4) was approximately 200 m long, 1 m wide, and clearly marked with white engineer tape on the left and right sides. The Soldiers teleoperating the robot used a bounding movement to negotiate the course along with the robot. The course was designed with

obstacles that masked the Soldiers' view of the robot, forcing them to maneuver the robot using only the driving camera and display. The obstacles included a tunnel, hills, a covered area, and tents. Three transition points were marked with red flags. The transition points marked the locations where the Soldiers maneuvered the robot from a location behind them to one in front of them in order to reconnoiter the lane.

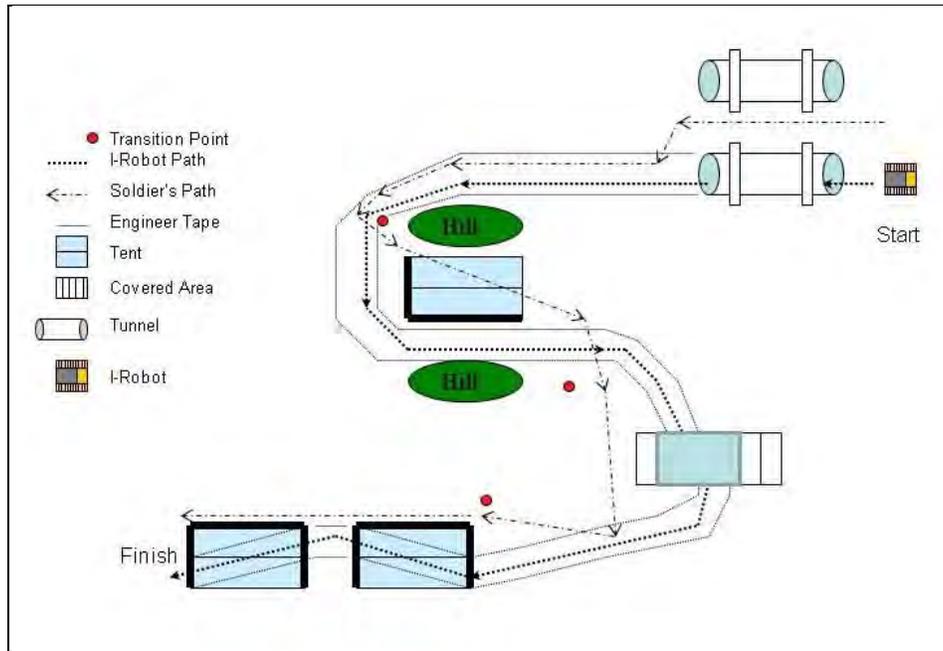


Figure 4. Outdoor robotic course.

### 2.2.4 Indoor Robotic Driving Course

The building reconnaissance course (figure 5) was established at the HRED facility at the McKenna military operations in urban terrain site at Fort Benning. It consisted of a one-story building with one large partitioned room. Tables, chairs, computers, and other furnishings were placed at varying locations along the reconnaissance route in order to increase the difficulty of negotiating the route.

Soldier operators were located out of the line of sight of the robot at a stationary position inside a tent near the building. Based on data obtained from a LADAR sensor, the robot's obstacle detection and avoidance algorithm was used during the indoor trials. This algorithm is designed to assist in teleoperation by detecting obstacles within the path of the robot and navigating the robot to open areas. The intended result is to provide an obstacle avoidance behavior to assist the operator in space-constrained navigation (Pierce et al., 2010).



mission that they would undertake during the experiment. The training and robotic courses were also explained, and any questions the Soldiers had concerning the experiment were answered.

### **2.3.2 Training**

A representative from CISD trained the Soldiers on the use of the PackBot. Soldiers practiced teleoperating the robot on the same courses used during the experiment to help mitigate learning effects. They were trained on each controller just before executing the course with that controller. Soldiers were considered trained once they were able to complete the training course without assistance. The average training time required was 35 min. Questionnaires concerning the amount of practice time given, the level of detail presented, and the adequacy of training aids were administered at the completion of training.

### **2.3.3 Robotic Course Iterations**

Soldiers negotiated each of the robotic driving courses twice, once using each of the OCU configuration types. Both the robot and the Soldiers teleoperating the robot negotiated the outdoor course. The Soldier advanced through the course using a bounding method, alternating between foot movement, and teleoperating the robot from a stationary position. The Soldier moved to a predetermined transition point first and then maneuvered the robot past his position to the next transition point. He moved up to the next transition point before continuing teleoperation of the robot. The operator continued bounding between transition points until reaching the end of the course. Upon completion of the outdoor course, the operator moved to a stationary control station set up outside the indoor driving course and executed the indoor driving course using the same controller. Soldiers completed two iterations, one with each controller type on each course for four runs. Data collectors recorded the times to complete each course, the number of times the robot went off course (outside the boundaries), and the number of driving errors committed. The operator was given a “forward” driving error for causing the robot to hit an object when maneuvering the robot forward. If an object was hit when the robot was reversing, a “rear” driving error was recorded. Upon completing each iteration, the Soldiers were given a questionnaire designed to assess their performance and experiences with each of the control systems. The participants also completed the NASA-TLX. Half of the Soldiers used the Android controller first and half used the Xbox 360 controller first.

### **2.3.4 End of Experiment Questionnaire**

After completing both courses, the Soldiers completed an end-of-experiment questionnaire that compared each of the controllers on a number of characteristics. They also completed questionnaires concerning the information requirements for teleoperating the robot.

## **2.4 Experimental Design**

### **2.4.1 Independent Variable (Within Subjects)**

- Controller type

### 2.4.2 Dependent Variables

- NASA-TLX workload scores
- Course completion times
- The number of times the driver went off course
- The number of driving errors on the course (forward and rear)
- Data collector comments
- Questionnaire comments

### 2.5 Data Analysis

All objective data were analyzed using paired sample *t*-tests. Cohen's *d*, a measure of effect size, was computed for each *t* value. Cohen's *d* is the difference between the means divided by the pooled standard deviation. Sequence effects were controlled through the counterbalanced order of the experimental design. Soldier questionnaire data were analyzed using descriptive statistics on the subjective ratings.

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## 3. Results

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### 3.1 Demographics

The Soldiers ranged in rank from E4 to E5. The average age of the Soldiers was 30 years, and the average time in service was 33 months. None of the Soldiers had any prior military experience in teleoperating a ground unmanned robot. Detailed responses to the demographics questionnaire are available in appendix A.

### 3.2 Training

The participants rated the training as being very good for both controller types. Learning to operate the controls and drive the robot was easy for both controllers. The Soldiers indicated that the hardest task to learn was controlling the robot's speed when turning using the Android controller. Several Soldiers commented that the simplicity of the Android made it easy to learn to use. Detailed responses to the training questionnaire are available in appendix B.

### 3.3 Robotic Course Results

Table 1 and figure 6 show the mean course completion times for the two controllers. Mean times with the Xbox were significantly faster than the mean times for the Android on both the outdoor [ $t(29) = 6.90, p < 0.001, d = 1.53$ ] and indoor [ $t(29) = 9.15, p < 0.001, d = 1.89$ ] courses.

Table 1. Mean course completion times (min:s).

	Xbox		Android	
	Outdoor	Indoor	Outdoor	Indoor
Mean	4:35	2:42	7:20	4:38
SD	0:59	0:38	2:21	1:17

Note: SD = standard deviation.

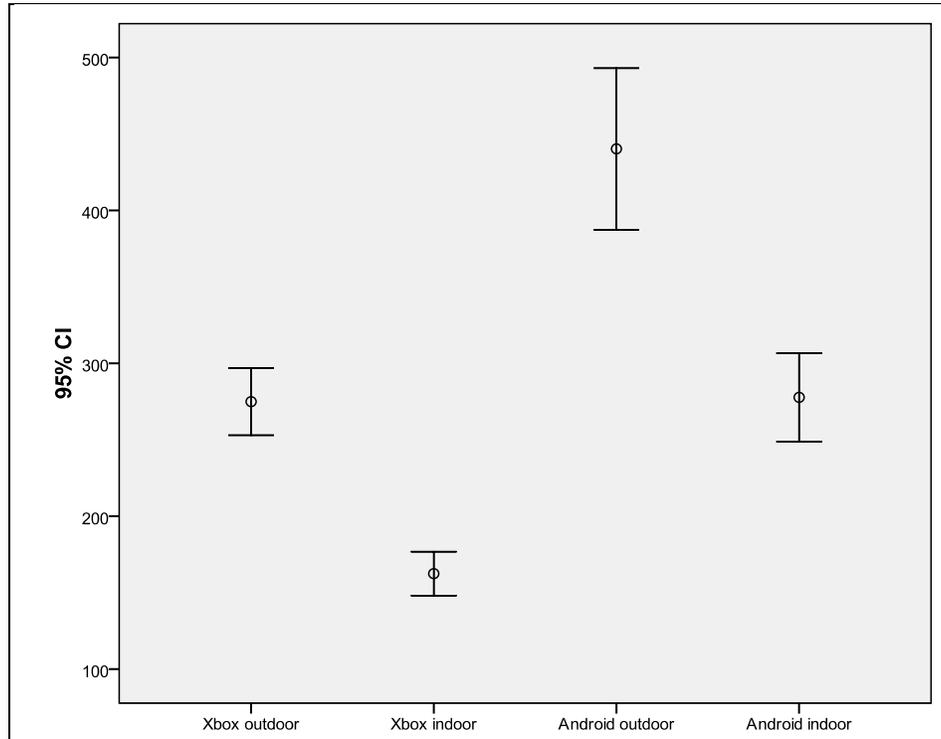


Figure 6. Mean course completion times with 95% confidence intervals.

The mean number of off-course errors for both controllers on the outdoor course is shown in table 2 and in figure 7. There were significantly fewer errors with the Xbox than with the Android,  $t(29) = 5.53, p < 0.001, d = 1.15$ .

Table 2. Mean number of off-course errors, outdoor course.

	Xbox	Android
Mean	4.23	10.17
SD	3.76	6.22

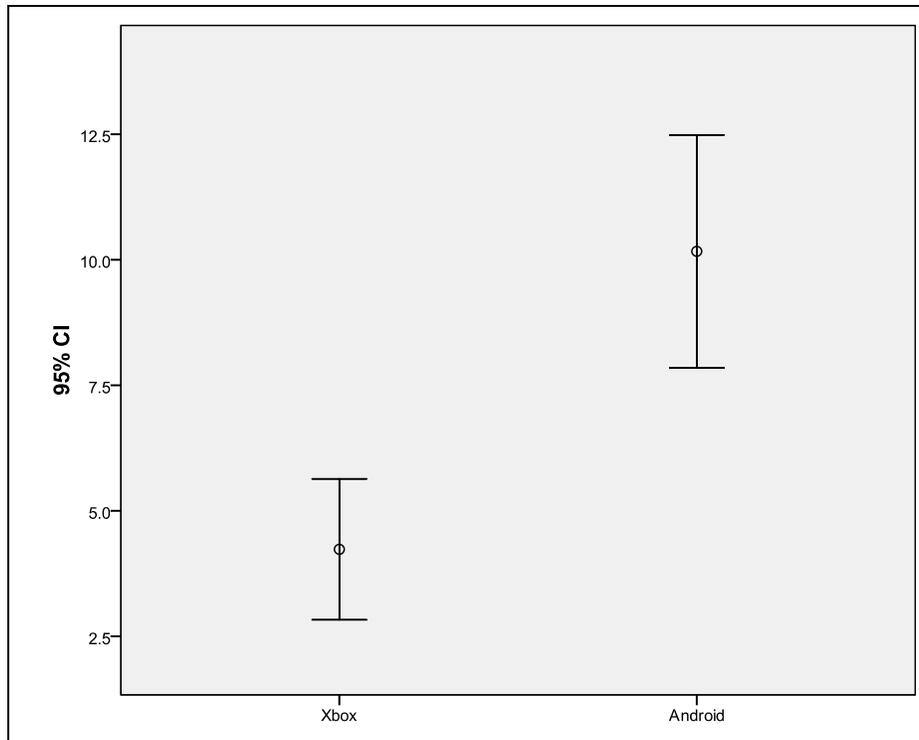


Figure 7. Mean off course errors with 95% confidence intervals.

Table 3 and figures 8 and 9 show the mean number of forward- and rear-driving errors on the indoor and outdoor courses. As shown in table 4, there were significantly fewer forward and rear errors on both courses with the Xbox controller.

Table 3. Mean number of driving errors.

	Xbox				Android			
	Outdoor		Indoor		Outdoor		Indoor	
	Forward	Rear	Forward	Rear	Forward	Rear	Forward	Rear
Mean	3.20	0.20	1.03	2.13	7.37	1.47	2.97	3.90
SD	3.43	0.41	1.77	2.80	4.24	1.63	2.40	2.96

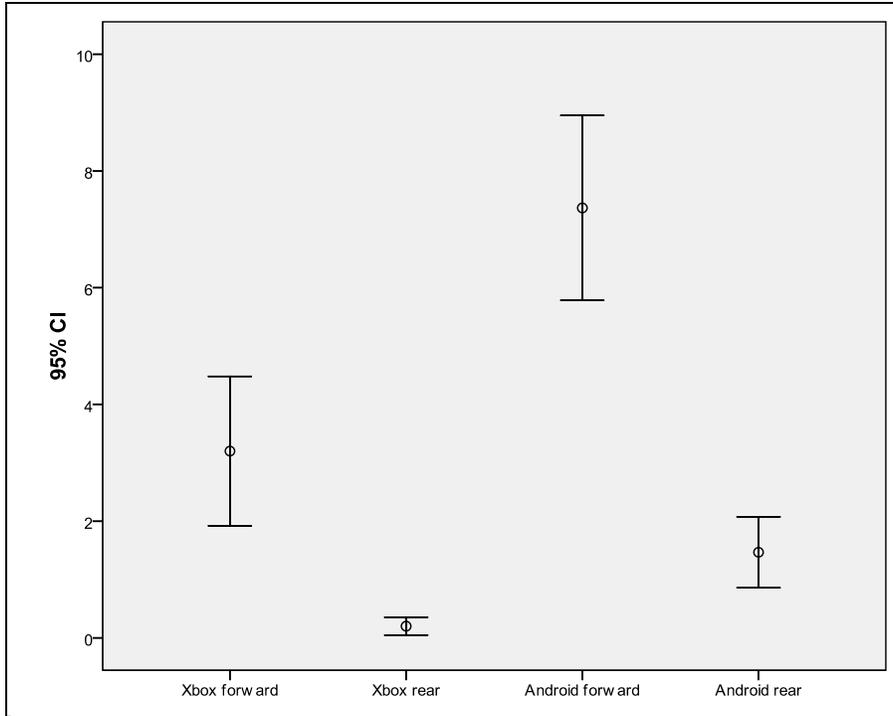


Figure 8. Mean outdoor driving errors with 95% confidence intervals.

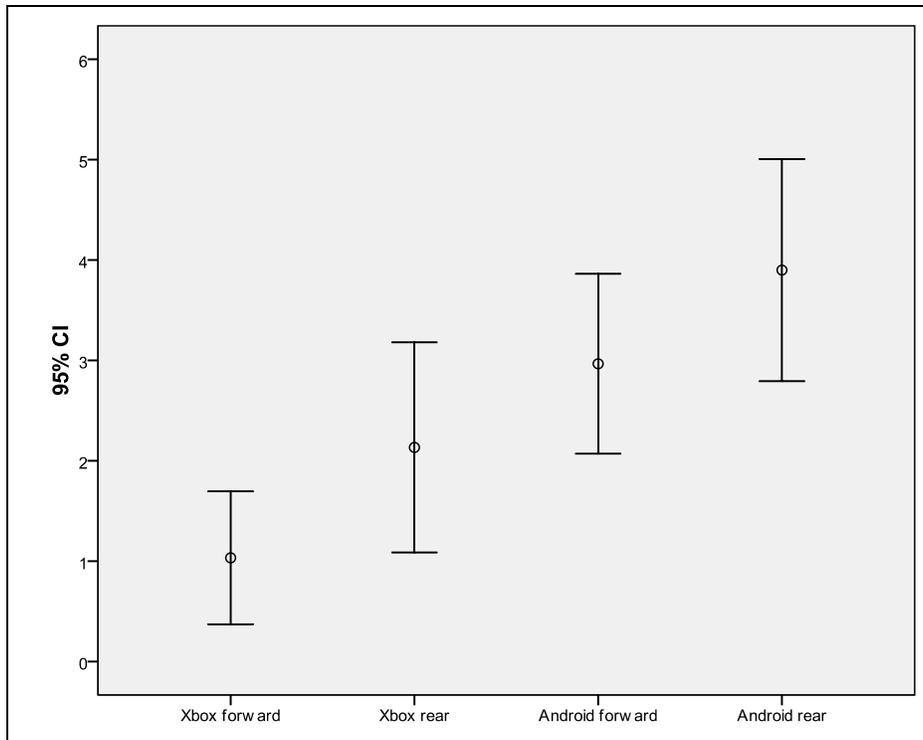


Figure 9. Mean indoor driving errors with 95% confidence intervals.

Table 4. Summary of t-tests, driving errors.

<b>Variable</b>	<b><i>t</i></b>	<b>df</b>	<b><i>p</i></b>	<b><i>d</i></b>
Outdoor forward driving errors	-5.19	29	<0.001 <sup>a</sup>	1.08
Outdoor rear driving errors	-4.13	29	<0.001 <sup>a</sup>	1.06
Indoor forward driving errors	-5.12	29	<0.001 <sup>a</sup>	0.92
Indoor rear driving errors	-3.4	29	0.002 <sup>a</sup>	0.61

<sup>a</sup>p <0.05, two-tailed.

It is interesting to note that for the indoor trials, more rear errors were made with both types of controllers than forward errors. This is because the guarded teleoperation worked mostly in the front of the robot (approximately 240°). When errors without the guarded teleoperation (outdoors forward and indoors and outdoors rear) are compared to errors with the guarded teleoperation (indoors forward), there is an indication of the benefit provided by the guarded teleoperation mode.

### 3.4 NASA-TLX Results

Table 5 shows the means of the NASA-TLX scales as well as the total workload means. The paired sample t-tests summarized in table 6 indicate that the workload was significantly higher for the Android relative to the Xbox on the mental, effort, and frustration scales and in terms of total workload. The physical workload was quite small for both controllers. The total workload means are shown in figure 10, and the scale means are shown in figure 11.

Table 5. Scale means and total workload means, NASA-TLX.

<b>Scale</b>	<b>Android</b>		<b>Xbox</b>	
	<b>Mean</b>	<b>SD</b>	<b>Mean</b>	<b>SD</b>
Mental	67.0	19.9	40.2	22.0
Physical	33.7	26.7	23.7	18.6
Temporal	62.7	15.9	43.0	22.4
Performance	53.3	21.7	29.5	21.8
Effort	59.3	23.7	30.8	18.0
Frustration	63.0	25.0	26.8	19.6
Total workload	61.4	17.6	36.2	16.4

Table 6. Summary of t-tests, NASA-TLX.

<b>Scale</b>	<b><i>t</i></b>	<b>df</b>	<b><i>p</i></b>	<b><i>d</i></b>
Mental	7.49	29	<0.001 <sup>a</sup>	1.28
Physical	2.06	29	0.048 <sup>a</sup>	0.44
Temporal	6.26	29	<0.001 <sup>a</sup>	1.01
Performance	4.65	29	<0.001 <sup>a</sup>	1.09
Effort	7.06	29	<0.001 <sup>a</sup>	1.36
Frustration	9.55	29	<0.001 <sup>a</sup>	1.61
Total	8.60	29	<0.001 <sup>a</sup>	1.48

<sup>a</sup>p <0.05, two-tailed.

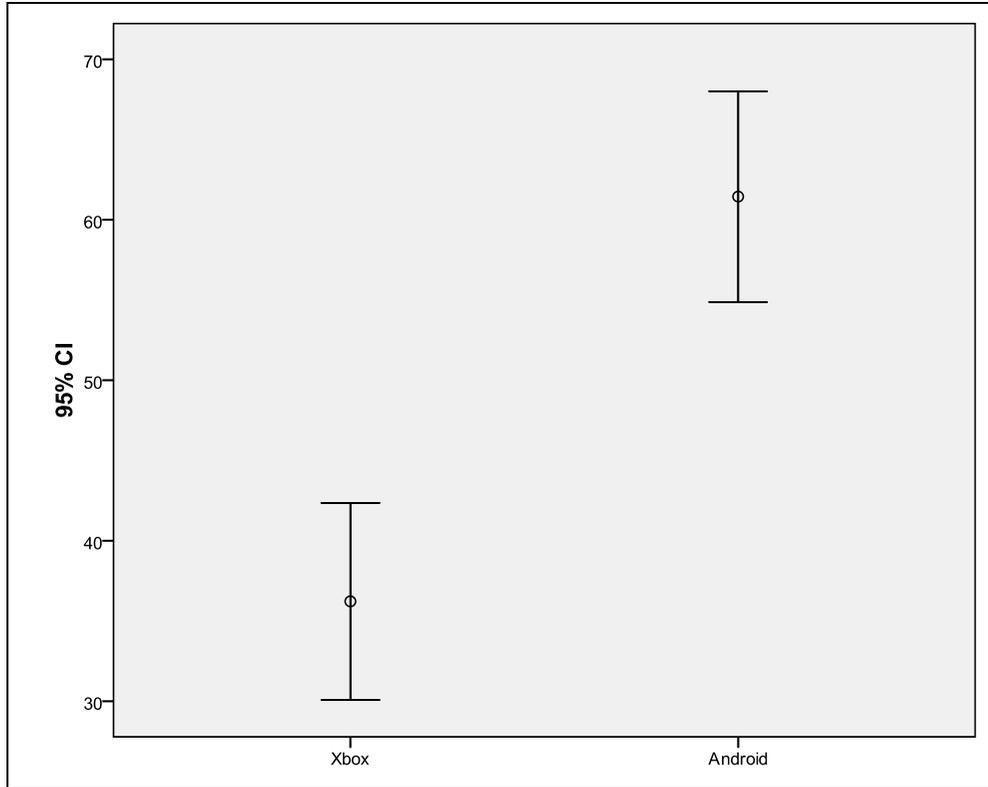


Figure 10. NASA-TLX total workload means with 95% confidence intervals.

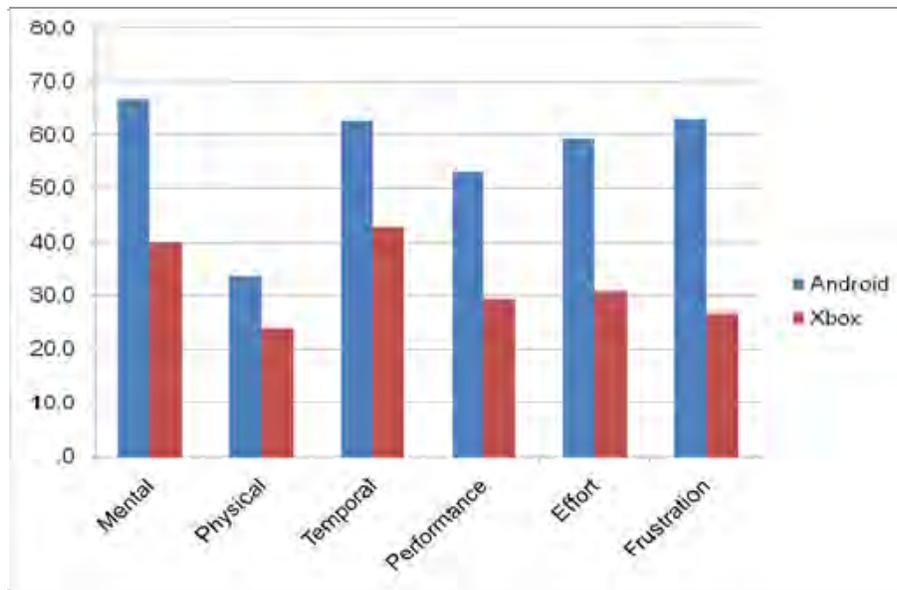


Figure 11. NASA-TLX scale means with 95% confidence intervals.

### 3.5 Questionnaire Results

Upon completion of the outdoor and indoor courses, Soldiers were asked to rate their ability to perform the robotic maneuver tasks using each controller. The tasks were rated using a 7-point scale, with 1 being extremely difficult and 7 being extremely easy. Table 7 shows the maneuver tasks and ratings for each controller. All of the tasks were easier to perform with the Xbox than with the Android controller.

Table 7. Maneuver task ratings.

Maneuver Tasks	Mean Response	
	Xbox	Android
Move in the correct direction (outside unguarded configuration)	5.50	3.27
Move in the correct direction (inside guarded configuration)	5.57	3.37
Avoid obstacles (outside unguarded configuration)	5.13	3.30
Avoid obstacles (inside guarded configuration)	5.20	3.63
Identify any terrain features that might have an adverse effect on the ability of the robot to maneuver through the course	4.90	4.07
Anticipate whether the turn radius of the vehicle will allow a turn	4.70	3.70
Identify if you are on the course	4.83	4.32
Maintain control when driving at slowest speeds	6.07	4.30
Maintain control when driving at medium speeds	5.53	3.55
Maintain control when driving at fastest speeds	4.47	2.33
Return to the correct route after navigating around obstacles	5.07	3.67
Overall ability to perform driving tasks	5.50	3.47
Overall controller rating	5.93	3.72

Twenty-six of the 30 participants stated they preferred the Xbox controller to the Android controller. Two preferred the Android, and two had no preference. Several Soldiers commented that their preference for the Xbox controller was based on their familiarity from previously playing video games. Others stated the haptic feedback they got from manipulating the Xbox controller toggle allowed them to control the robot's speed better than the Android's touch-screen toggle. Adjusting to the sensitivity of the Android's touch-screen toggle control was considered to be the hardest task to learn.

The Android display was used to view the driving camera video in both conditions. For both controller conditions, Soldiers stated they had difficulty viewing the Android's screen in direct sunlight. The robot's driving camera also provided a dark image when cloud cover caused low-light level conditions. During the Xbox trials, Soldiers were required to either set the display down on something or hold the Android display with one hand and manipulate the Xbox controller with the other. Many Soldiers stated they would prefer the display to be attached to the controller.

The Soldiers liked the Android's overall design and stated that its simplicity made learning to use it easy. They also liked its compact size, light weight, and being able to operate the robot with one hand. They did state that the size of the screen was sometimes a problem because of inadvertent activation of adjacent controls. One Soldier stated that it was difficult to get the

screen controller to register the actual position of the user's finger. The sensitivity of the touch controller also made it difficult for them to maintain smooth, steady operation and made overcorrection a common problem. Steering while maintaining speed was also identified as a problem with the touch controller. Several Soldiers stated that their performance with the Android controller would most likely improve with more practice.

Detailed responses to the post-iteration and end-of-experiment questionnaires are available in appendices C and D.

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## **4. Discussion and Recommendations**

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The Xbox controller was demonstrated to be good for controlling robotic driving tasks because total course completion times, driving errors, and off-course errors were significantly better. This finding is consistent with the findings of other military designers who have successfully mapped the Xbox controller to robot driving functions (Pettitt et al., 2008; Cheung, 2008; Hodge, 2009; Wright, 2010). The Xbox controller has been demonstrated to be easy for dismounted Soldiers to use because of its size, weight, and design (Pettitt et al., 2008). The rubber thumb sticks are intuitive for driving the robot; this is especially true for the many Soldiers who frequently play video games using the Xbox controller.

The Android touch screen used during this experiment was extremely sensitive, creating many driving errors and requiring the robot to be backed up frequently for repositioning. This increased course completion times. Also, the screen and buttons were fairly small, and many errors were made because of inadvertent button activation. The scaled-down control also contributed to the sensitivity issue. The virtual joystick needed to control the robot at both slow speeds for maneuverability and fast speeds to overcome terrain such as loose, wet grass. With relatively small screen real estate, the extreme difference between minimum and maximum speed had to be controlled within a small area. Other more autonomous control approaches for robotic supervisory control might prove more fruitful for touch control. For example, Mark Micire successfully used the Microsoft Surface touch screen to guide swarm robots (Saenz, 2010). His touch-screen program gave operators different levels of control, many of which were supervisory control levels. He also used the touch screen for more direct control of individual robots. However, the touch interface for direct human control was much larger and more sophisticated than the interface on the Android used during this experiment. Haas et al. (2010) used touch control for swam robots too. In their experiment, touch was used to define the location of the map object and not for direct driving.

While the Android touch screen was not as successful as the Xbox controller for direct driving, other instantiations of touch-screen control might prove more successful. For example, a more successful touch-based interface might require larger buttons to accommodate human fingers and

buttons that are placed farther apart than the Android allowed. Adams and Kaymaz-Keskinpala (2004) and Keskinpala et al. (2003) experimented with a PDA-based touch interface for gloved finger interactions. This interface had to have larger-than-normal touch-screen buttons for commanding the robot; this used a lot of the PDA display space. The space conflict issue was addressed by providing buttons that were transparent and, thus, they maximized the use of available space on the display screen. Also, incorporating haptic or audio feedback into the touch screen could potentially assist the operator in knowing when the control is engaged since this was a frequently cited problem. Lundberg et al. (2003) found that the lack of haptic feedback forced the user to move his or her vision from the robot driving information to the control screen. The reverse might also be true that if the operator does not move his or her vision from the driving display, it could create more errors during operation. Thus, some type of feedback should be provided.

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## **5. Conclusion**

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The Android could be used to successfully teleoperate a robot. The primary benefit is the small interface that minimizes the equipment burden of the Soldier. Soldiers provided positive comments about its small size, light weight, and one-handed use, stating that the form of the controller was excellent for dismounted operations. However, costs in terms of time and errors are expected beyond those found with other more physical type controls such as the Xbox. Other larger touch-screen interfaces that incorporate haptic or auditory feedback might prove more successful for direct teleoperation. Also, the Android touch screen might be more successful when used for more supervisory control functions. Further testing with more in-depth performance evaluation could also be used to recalibrate the virtual joystick to a more useable status by modifying top speed, turning rate, and acceleration.

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## 6. References

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- Adams, J.; Kaymaz-Keskinpala, H. Analysis of Perceived Workload When Using a PDA for Mobile Robot Teleoperation. *Proceedings of the International Conference on Robotics and Automation*, New Orleans, LA, 2004.
- Barnes, M. J. U.S. Army Research Laboratory: Fort Huachuca, AZ. Personal correspondence, 2006.
- Chen, J. C.; Haas, E. C.; Pillalamarri, K.; Jacobson, C. N. *Human-Robot Interface: Issues in Operator Performance, Interface Design, and Technologies*; ARL-TR-3834; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2006.
- Cheung, H. IPone and Xbox 360 controller commands DARPA's Killer "Crusher" Robot. *Tom's Hardware*; <http://www.tomshardware.com/news/iphone-xbox-360-controller-commands-darpa-s-killer-crusher-robot,4879.html> (accessed 2008).
- Fong, T.; Thorpe, C.; Glass, B. PDA Driver: A Handheld System for Remote Driving. *IEEE International Conference on Advanced Robotic* (Coimbra, Portugal); <http://vrai-group.epfl.ch/papers/ICAR03-TF.pdf> (accessed 23 February 2004).
- Hart, S. G.; Staveland, L. E. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In *Human Mental Workload*; Hancock, P. A., Meshkati, N., Eds.; Amsterdam: North-Holland, 2008; pp 139–183.
- Haas, E. C.; Fields, M.; Stachowiak, C.; Hill, S.; Pillalamarri, K. *Extreme Scalability: Designing Interfaces and Algorithms for Soldier-Robotic Swarm Interaction, Year 2*; ARL-TR-5222; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2010.
- Hodge, N. Future warbot powered by Xbox controller. *Danger Room*; <http://www.wired.com/dangerroom/2009/06/future-warbot-powered-by-xbox-controller/> (accessed 2009).
- Kamsickas, G. *Future Combat Systems (FCS) Concept and Technology Development (CTD) Phase—Unmanned Combat Demonstration*; Technical Report D786-1006102; The Boeing Company: Seattle, WA, 2003.
- Keskinpala, H. K.; Adams, J. A.; Kawamura, K. PDA-Based Human-Robotic Interface. *IEEE* **2003**, 3931–3936.
- Lundberg, C.; Barck-Holst, C.; Folkesson, J.; Christensen, H. I. PDA Interface for a Fielded Robot. *Proceedings of the 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Las Vegas, NV, 2003.
- Merlo, J. U.S. Army: West Point, NY. Personal correspondence, 2006.

- O'Brien, B.; Stump, E.; Pierce, C. Effects of Increasing Autonomy on Tele-Operation Performance. *Proceedings of the 2010 IEEE International Conference on Intelligent Robots and Systems (IROS)*, Taipei, Taiwan, 2010.
- Pettitt, R. A.; Redden, E. S.; Carstens, C. B. *Scalability of Robotic Controllers: An Evaluation of Controller Options*; ARL-TR-4457; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2008.
- Pierce, C.; Baran, D.; Bodt, B. Experimental Evaluation of Assistive Behaviors for Man-Portable Robots. *Proc. SPIE Unmanned Systems Technology XII*, April 2010.
- Quigley, M.; Goodrich, M. A.; Beard, R. W. Semi-autonomous Human-UAV Interfaces for Fixed-wing Mini-UAVs. *Proceedings of IROS 2004*; <http://faculty.cs.byu.edu/~mike/mikeg/papers/QuigleyGoodrichCIROS2004.pdf> (accessed 26 August 2004).
- Saenz, A. Multitouch Control Screen Turns Swarm Robotics Into a Game of StarCraft. *Singularity Hub*; <http://singularityhub.com/2010/09/01/multitouch-control-screen-turns-swarm-robotics-into-a-game-of-starcraft-video/> (accessed 2010).
- Sekmen, A.; Koku, A. B.; Zein-Sabatto, S. Human Robot Interaction Via Cellular Phones. *Proceedings of the IEEE Conference on Systems, Man and Cybernetics*, 2003; pp 3937–3942.
- Setalaphruk, V.; Ueno, A.; Kume, I.; Kono, Y. Robot Navigation in Corridor Environments Using a Sketch Floor Map. *Proceeding of the 2003 IEEE International Symposium on Computation Intelligence in Robotics and Automation*, Kobe, Japan; pp 552–557; <http://ai-www.naist.jp/papers/setala-v/EX/CIRA2003/Paper/cira2003-setalav.pdf> (accessed 23 September 2005).
- Skubic, M.; Bailey, C.; Chronis, G. A Sketch Interface for Mobile Robots. *Proceedings of the 2003 IEEE International Conference on Systems, Man, and Cybernetics*, 2003; pp 919–924.
- Veronka, N.; Nestor, T. *Integrated Head-Mounted Display Interface for Hands-Free Control*; SBIR report no. ADB264384; Cybernet Systems Corp.: Ann Arbor, MI, 2001.
- Wright, M. IRobot Packbot Gallery: Xbox 360 Controller Goes to War. *Electricpig*; <http://www.electricpig.co.uk/2010/10/15/irobot-packbot-gallery-xbox-360-controller-goes-to-war> (accessed 2010).

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## **Appendix A. Demographics**

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This appendix appears in its original form, without editorial change.

**SAMPLE SIZE (N) = 30**

<u>MOS</u>		<u>RANK</u>	<u>AGE</u>	<u>DUTY POSITION</u>	
09S – 19	73C – 1	E-4 – 8	30 years	OCS	– 12
18F – 1	77F – 1	E-5 – 14	(mean)	G4	– 2
19K – 1	91S – 1	NR – 8		Intel Analyst	– 1
25B – 1	NR – 4			Plt SGT	– 1
35F – 1				Trans Off	– 1
				NR	– 13

1. How long have you served in the military? 33 months (mean)
2. How long have you had an infantry-related job? 34 months (mean) (N = 5)
3. How long have you been a fire team leader? 15 months (mean) (N = 3)
4. How long have you been a squad leader? 10 months (mean) (N = 4)
5. How long have you been deployed overseas? 25 months (mean) (N = 10)
6. How long have you been deployed in a combat area? 12 months (mean) (N = 7)
7. With which hand do you most often write? 25 Right 5 Left
8. With which hand do you most often fire a weapon? 26 Right 4 Left
- 9.a. Do you wear prescription lenses? 15 No 15 Yes
  - b. If so, which do you most often wear? 9 Glasses 4 Contacts 2 Both
  - c. Which is your dominant eye? 21 Right 8 Left 1 NR

10. Please rate your skill level for each of the following activities?

**None**                      **Beginner**                      **Intermediate**                      **Expert**  
**1**                                      **2**                                      **3**                                      **4**

<b>ACTIVITY</b>	<b>MEAN RESPONSE</b>
Operating ground unmanned vehicles	1.54
Operating aerial vehicles	1.25
Target detection and identification	1.79
Playing commercial video games	2.79
Training with Army video simulations	2.00

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## **Appendix B. Training**

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This appendix appears in its original form, without editorial change.

**SAMPLE SIZE = 30**

1. Using the scale below, please rate the following **training features** on the **Xbox Controller**:

1                      2                      3                      4                      5                      6                      7  
 Extremely bad    Very bad    Bad    Neutral    Good    Very good    Extremely good

	<b>MEAN RESPONSE</b>
Length of training	5.70
Level of detail	5.87
Hands-on practice	6.13
Overall quality of training	6.13

**Comments**

**No. of Responses**

Worked great.	2
Very easy to use.	4
User friendly.	1
Short, sweet, and to the point. No extra fluff.	1
Easy to pick up.	3
Liked using both hands.	1
Good example. Allowed for as much time as needed to practice.	2
Patient instructors.	1
Easy to use joystick.	1
Coming from a video game background, the training was very concise and almost self-explanatory.	3
Requires more turning capability.	1
Doesn't have to be as long.	1

2. Using the scale below, please rate the **training adequacy** that you received in the following areas with the **XBox Controller**:

1                      2                      3                      4                      5                      6                      7  
 Extremely bad    Very bad    Bad    Neutral    Good    Very good    Extremely good

<b>Xbox Controller</b>	<b>MEAN RESPONSE</b>
Understanding the display	6.10
Operating the controls	6.43
Driving the robot	6.17
Adequate time on the practice lane	6.31
Clarity of instructions	6.47
Understanding of tasks	6.50
Overall evaluation of the training course	6.30

<b><u>Comments</u></b>	<b><u>No. of Responses</u></b>
Great training.	1
Easy.	2
Broke it down to an easy level of understanding.	2
Instructions were clear and concise.	3
Well trained for task.	1
Given enough time and practice, any soldier could become proficient in its use.	1
Plenty of time to practice.	1
Glare from the sun.	1
No more training before testing would have improved my initial experience.	1
I felt I didn't need too much training.	1
Hard to hold.	1

3. What were the easiest and hardest training tasks to learn with **Xbox Controller**?

<b><u>Comments</u></b>	<b><u>No. of Responses</u></b>
<b><u>Easiest</u></b>	
Everything.	1
Pick up and go.	1
I have always had video games; this was just like it.	1
Working joystick.	3
Speed control.	4
Using controller.	5
Learning to control the robot.	1
Controlling robot direction.	3
Steering.	1
How to move.	1
The dead man's switch function.	1
Learning which button does what.	1
Manipulation of the controls.	1
Overall controls were easy to use.	1
Maneuvering robot.	3
Maneuvering around corners.	1
Driving forward.	1
Turning.	1
Going in straight directions.	1
Maintaining speed.	1
Maintaining at low speed.	1
Most soldiers already know how to use the controller; not much training is needed.	1
<b><u>Hardest</u></b>	
Making the movements. It takes getting used to.	1
Not rushing.	1
Dealing with cords.	1

<u>Comments</u>	<u>No. of Responses</u>
Glare from sun (outside was difficult but still easier than Android).	1
Judging how far obstacles were from the robot.	1
Identifying course.	1
Learning to control the joystick.	2
Pressing buttons correctly.	1
Holding both the screen and the controller (while maintaining a weapon).	2
Hard to know how to hold all the components.	1
Adjusting to the video.	1
Having to use both hands.	1
Turning on point.	1
Turning response.	1
Turning while stopped.	1
Turn while moving.	1
A lot more equipment to carry.	1
Maintain control at high speed.	1

4. Using the scale below, please rate the following **training features** on the **Android Controller**.

1                      2                      3                      4                      5                      6                      7  
 Extremely bad    Very bad    Bad    Neutral    Good    Very good    Extremely good

	<b>MEAN RESPONSE</b>
Length of training	5.77
Level of detail	5.83
Hands-on practice	5.83
Overall quality of training	5.90

<u>Comments</u>	<u>No. of Responses</u>
Easy instruction.	2
Everything thing was shown in a detailed manner.	1
Training was professional and insightful.	1
Training was good and needed.	1
Instructors gave good input about what worked for them.	1
Light and easy to carry.	2
Adequate.	1
A challenging subject to train.	1
Having previously had a touch screen, the training made sense and was clear and concise.	1
Needed a little more time to familiarize myself with the controls.	1
Need a lot more training to achieve same goal. Larger learning curve than Xbox.	1
Tough to use; however, with more fine turning, the Android may be the one to use.	1

**Comments**

**No. of Responses**

Hated it. Training was fine.	1
Weak response; too sensitive on controls for operation.	1
Learning to control.	1
Needs a bigger control panel.	1
Using the phone was made difficult by having big thumbs.	1

5. Using the scale below, please rate the **training adequacy** that you received in the following areas with the **Android Controller**:

1                      2                      3                      4                      5                      6                      7  
 Extremely bad    Very bad    Bad    Neutral    Good    Very good    Extremely good

<b>Android Controller</b>	<b>MEAN RESPONSE</b>
Understanding the display	5.93
Operating the controls	4.93
Driving the robot	4.83
Adequate time on the practice lane	5.80
Clarity of instructions	6.03
Understanding of tasks	6.20
Overall evaluation of the training course	5.87

**Comments**

**No. of Responses**

Excellent job.	2
Great communication and explanation of controller.	1
Training was good.	2
Clear and concise.	1
Adequate training.	4
Fine.	1
Liked having practice before the actual run,	1
It was easy, the touch screen was personally harder to master as a controlling system.	1
Outside the picture clarity was poor.	1
Controller just needs some tweaking.	1
Need to have sensitivity set up to the individual person.	1
Too touchy on touchscreen for the Android.	1
Difficult to maneuver because the joystick was too small.	1
Device was hard to utilize.	1
I think it might be better to replace the Android with an iPod.	1
Just need a lot more practice.	1

6. What were the easiest and hardest training tasks to learn with **Android Controller**?

<b><u>Comments</u></b>	<b><u>No. of Responses</u></b>
<b><u>Easiest</u></b>	
The way to operate it.	4
Its portability.	1
User interface.	1
Understanding the controls.	3
Controlling the robot was easy.	2
General movement of the robot was easy.	3
Driving at slow speeds.	1
Turning at moderate speed.	1
Reading monitor.	2
The display was simple and easy to understand.	4
Backing up.	1
Joystick was easy but it was too small for my fingers. It might work better if it was bigger.	1
Moving the flippers.	1
One hand was easy to use and maneuver.	1
Controlling adjustable tracks.	1
<b><u>Hardest</u></b>	
Too touchy. Sensitivity needs to be toned down.	8
Controlling the touch control. A slight touch and off course or too fast.	1
Making small, subtle course corrections. It has a tendency to over correct.	1
Operating the Android.	4
Steering and control of the robot.	2
Keeping the robot on a straight path at medium-high speeds.	1
Going forward and maintaining control at high speeds.	1
Direction and speed control.	3
Can't turn and maintain speed.	1
Turning at slow/fast speeds.	3
Operating the robot with one finger on a touch pad.	1
Small touch screen.	1
Needs a bigger control panel area.	1
Not hitting the other buttons on the screen while trying to control the robot.	1
What makes the Android harder to control is the narrowness of the pad.	1
Coordinating finger movement on the touch screen with robotic movement. I was very jumpy for both runs.	1
Knowing how much time/pressure to apply to screen. Gentle taps versus holding your thumb down.	1
Making the screen display work with thumb touch.	1
The touch screen joystick.	1
Maneuvering in close spaces.	1
Difficult to back robot up and return to forward.	2
Adapting to new technology is a challenge.	1

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## **Appendix C. Post Iteration**

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This appendix appears in its original form, without editorial change.

**SAMPLE SIZE = 30**

1. Using the scale below, please rate your ability to perform each of the following **tasks** based on your experience with the display that you just used:

1                      2                      3                      4                      5                      6                      7  
 Extremely difficult    Very difficult    Difficult    Neutral    Easy    Very easy    Extremely easy

<b>NAVIGATION TASKS</b>	<b>MEAN RESONSE</b>	
	<b>Xbox</b>	<b>Android</b>
Move in the correct direction (outside unguarded configuration)	5.50	3.27
Move in the correct direction (inside guarded configuration)	5.57	3.37
Avoid obstacles (outside unguarded configuration)	5.13	3.30
Avoid obstacles (inside guarded configuration)	5.20	3.63
Identify any terrain features that might have an adverse effect on the ability of the robot to maneuver through the course	4.90	4.07
Anticipate whether the turn radius of the vehicle will allow a turn	4.70	3.70
Identify if you are on the course	4.83	4.32
Maintain control when driving at slowest speeds	6.07	4.30
Maintain control when driving at medium speeds	5.53	3.55
Maintain control when driving at fastest speeds	4.47	2.33
Return to the correct route after navigating around obstacles	5.07	3.67
Overall ability to perform driving tasks	5.50	3.47

**Comments**

**Xbox**

**No. of Responses**

Great.	1
Great training experience.	1
Very easy to use.	2
Much easier than the Android.	3
Very simple.	1
Easier mainly because I play video games.	1
Was familiar and toggles were easy to use with practice.	1
Extremely easy to maneuver the robot on the course.	1
Robot responded well.	1
I preferred this controller.	1
With much less time to practice, this form of command can be easily mastered.	1
Once the driver adjusts to visual and speed controls and how they relate, the robot becomes more maneuverable.	1
The pivot steer could use a little more power to increase the speed of the course.	1
Speed control would be helpful.	1
Inside track a little slower response time when turning.	1
Turning was only problem.	2
Display is too small, but still manageable.	1

<u>Comments</u>	<u>No. of Responses</u>
An easier control to operate.	1
Video console should be mounted on controller.	1
Sensor on the inside got in the way at times from making turns that would have been easily accomplished manually.	1
Easier inside for lack of glare from sun.	1
Sometimes difficult to tell if you are on course in direct sunlight.	1
Outside was harder to identify course outlines in long grass.	1
Difficult to see screen outside when cloudy (camera was not letting in enough light).	1
Difficulty in viewing screen outdoors creates problems in keeping robot on course.	2
<b><u>Android</u></b>	
Enjoyed the sensor for walls/objects.	1
Task performance was fairly easy. More practice will render it easier.	1
Very convenient, i.e., it's small and functional. With the turning, the Android can be successful.	1
Virtual joystick was difficult to adapt to. Sometimes minor movements would achieve results and other times extreme movement would be required.	1
Somewhat easier outside once I got the hang of it. May have been because it was one solid unit vs. the two units with the Xbox.	1
Harder to control.	1
This controller seems incredibly impractical.	1
It was difficult to maintain a steady pace without overcorrecting.	1
Turning control unsteady.	1
Very difficult to turn, especially to the right.	1
Very difficult to make subtle course corrections.	1
Difficult to turn in own radius.	1
Control was very frustrating to get robot to turn properly as well as to control speed.	1
Seems rather difficult to get the screen controls to register actual position of the user's finger.	1
Felt that I did what was required in a timely manner for the amount of minimal training.	1
Would do well with more practice.	1
Lack of practice coordinating finger movement on the touch pad, as well as traveling at fast speeds.	1
Turn down sensitivity.	2
Larger touch screen.	1
Hard to see on screen.	1
Glare on the phone screen outside made it difficult to see.	1
Track area on phone very touchy; did better when I maintained contact with screen at all times.	1
Slight lag in controller to vehicle. Found controller challenging for me (never regularly use touch pad).	1

**Comments**

**No. of Responses**

Much more difficult than the Xbox.

1

2. Did you experience any of the following conditions?

	Number of Responses			
	Xbox*		Android	
	No	Yes	No	Yes
Eyestrain	23	6	22	8
Tunnel vision	28	1	27	3
Headaches	29	0	29	1
Motion sickness	29	0	29	1
Nausea	29	0	29	1
Disorientation	29	0	28	2
Dizziness	29	0	29	1

*\*One soldier did not give a response for the Xbox.*

**Comments**

**No. of Responses**

**Xbox**

No discomfort, just unfamiliarity with the system.

1

Eyestrain from glare from sun.

4

Because of sun, it was difficult to see the screen sometimes or even what the camera was projecting; especially when it was coming out of tunnel.

1

When facing the sun on emerging from the tunnel, the video feed seemed to have trouble adjusting to the light and was frequently blown out.

1

Eyestrain from small screen.

1

The screen clarity was an issue, but I'm sure it could be easily improved.

1

The goggle phone was easier to see, the HTC phone outside was not as clear.

1

The backpack was annoying.

1

Bulky; tough to run with weapon.

1

After covered obstacles camera took a few seconds to adapt to light.

1

**Android**

Eyestrain because difficult viewing screen.

1

Eyestrain, though not much true discomfort, it was just slightly difficult to orient the camera with the robot when traveling at fast speeds due to the size of the screen.

1

Still hard to see when going from dark to light places.

1

Screen a bit hard to see in certain angles in the sun.

1

Sensitivity of controls.

1

3. What were the easiest and hardest training tasks to learn with **this controller**?

**Comments****Xbox****No. of Responses****Easiest**

Everything.	2
Very easy to learn and use.	2
User interface.	1
If you play video games, it's pick up and go with this controller.	1
Joystick.	4
Maintain control at low speed.	1
It was significantly more maneuverable.	1
The controller was very easy to manipulate.	3
Very easy to give command to robot.	1
Simple use of controller; minimal manipulation needed.	2
Once I had a clear straight path, it was easy to pick up the pace and control the robot.	1
Maneuvering and controls was simple.	1
Controllers functions.	1
Controlling direction.	1
Control switches.	1
Turning was easiest.	1
Moving forward and backward.	1
To make it go straight.	2
Easy to see.	1
Nothing was easy.	1

**Hardest**

Operating at higher speeds.	2
Flaps.	1
Not pressing the flipper buttons accidentally.	1
Getting used to looking at screen on phone and then correlating on controller.	1
Seeing on the cell phone with the glare outside.	1
Hard to see in the shade.	1
Not accidentally touching the Android screen and causing the system to halt, and holding 3 objects at the same time -> screen, weapon, and controller.	1
Identifying distance from robot to oncoming obstacle.	2
It was hard not to rush through. All driving errors were because of rushing.	1
It was difficult to know what movements to make when the robot was facing a light source.	1
Would be easier to use if one joystick were acceleration and one for turning like a lot of driving games.	1
Turning ability.	1
Hard to turn and maintain any speeds.	1
Speed in relation to control.	1
Turning right or left on point.	1
Turns around trashcans.	1

<b><u>Comments</u></b>	<b><u>No. of Responses</u></b>
Backing up and avoiding obstacles.	1
Movement when making sharp turns.	1
Slow turns.	1
Recognizing I was off course; hard to see engineer tape.	1
To maneuver around terrain or just not being able to see the engineer tape via the camera because of the sun. This didn't happen often.	1
Hard to maintain with my gear.	1
Moving from one location to another while carrying all required equipment.	1
Getting back on track when I went off the course.	1
Carrying it around.	1

### **Android**

#### **Easiest**

Concept was easy to understand.	1
Using it.	1
Controls were very easy to get used to; they are simple.	1
Understanding how to move the robot.	1
It was just nice to have a hand-held controller.	1
User interface.	1
Getting back into program after exiting was easier.	1
Lightweight, portability.	3
One touch movement.	1
Camera worked great.	1
Correct yourself to the path.	1
Stationary turning.	1
Moving robot quickly.	1
Very little movement on controller to navigate.	1
Learning speed.	1
Navigating at slow speeds.	3
Navigation was easy in all directions.	2
Moving forward and bumper movements.	1
Easier to use on the outside obstacle than the inside.	1
Backing up was easy.	1
Gradually turn at moderate speeds.	1
Learning what the controller does.	2
Using sensor to my advantage.	1
Nothing was easy.	1

#### **Hardest**

Everything.	1
Utilizing the controller.	1
Sensitivity of controls.	5
Too sensitive.	3
The toggle was either too sensitive or it wouldn't respond in time.	1
Find the sensitivity on the controller as in relation to how robot actually moves. Once comfortable with sensitivity the controller is very easy to operate.	1

<u>Comments</u>	<u>No. of Responses</u>
Actually controlling it was very difficult.	2
Direction of controls.	1
Slight movements made robot go extremely fast making it difficult to maintain course.	1
Getting familiar with the turns.	1
Straight line speed was even difficult.	1
Turning without moving forward or backward.	1
Making left and right turns; touchy.	3
Much more difficult to turn right than left.	1
Maintaining the correct line. Losing control of the robot was fairly easy when on the outside. Inside was a little easier to maneuver.	1
Performing turns with robot.	2
Very difficult to turn in place.	1
The glare.	1
Going forward at higher speeds and staying in control.	2
Correct direction at high speeds.	1
Maintain a consistent line at high speeds.	1
Understanding the correlation between vehicle performance and finger movement on the touch screen at fast speeds.	1
To use the touch screen as a controller versus a knob. It was hard for me to control the speed and motion without the feeling or touch of my finger.	1
Getting it to do it.	1
I feel it would take a lot of practice before using it in the workforce.	1
Identify object/course.	1

4. Using the scale below, what is your **overall rating** of the controller that you used this iteration?

1                      2                      3                      4                      5                      6                      7  
 Extremely bad    Very bad            Bad                  Neutral              Good                Very good           Extremely good

<b>MEAN RESONSE</b>	
<b>Xbox</b>	<b>Android</b>
5.93	3.72

<u>Comments</u>	<u>No. of Responses</u>
	<u>Xbox</u>
Very good overall.	1
Good side for hands.	1
More control made it easier to adjust.	1
Controlled with ease.	1
Easy to use.	5
Significantly more practical.	1
I felt like I had a constant move the whole time on this controller, and things went much farther. This also allowed the obstacle avoidance system to	1

<u>Comments</u>	<u>No. of Responses</u>
drastically improve my time.	
With training, it would become very easy to utilize robot for intended purposes.	1
Using a controller people are familiar with makes operating the robot a simple task.	1
Works great if we can work on the stationary turning.	1
With exception of flipper buttons, quite easy to control.	1
Controller was easy to move robot; however, it was somewhat cumbersome to carry weapon and controller and camera simultaneously.	2
Also, back pack may create difficulty with carrying combat load.	
Clunky when outside with phone (display) controller, and backpack.	1
Two joysticks would be better.	1
Easier inside than outside.	1
Perhaps attach the screen to the Xbox.	1
Small screen, but very clear.	1
Traveling with cord was issue. Could detach from bag (but great that it is a quick reconnect).	1
Only concern re: light connect that automatic makes it appear like a "tunnel" which causes poorer visibility.	1
More practice needed.	1
<b><u>Android</u></b>	
It was fun.	1
The compactness, weight make it easy to take and move it with you.	2
Much more efficient to carry.	1
Controller is very good.	1
Some people need more time to adjust to it.	1
If you gain experience in using it, you can master it.	5
For someone with limited experience, it is a trial.	1
Think I might do better with a game control. Something more hands-on.	1
Too difficult with finger touch. Prefer a more hands-on system.	1
Would be better with practice.	1
It wasn't bad, but the Xbox was easier.	1
Not the best one for my background, though. I did adapt and get more proficient as the minutes went on.	1
Screen is a bit small, but gets the job done.	1
Other than getting comfortable with the sensitivity of the Android, it was really effective.	1
Easier outdoors than indoors.	1
I like the ease of just carrying a phone, but I would make the control surface a little larger and less sensitive.	1
I think you should consider the Android X instead of the Android HTC. X has 4.3" touch screen.	1
Very high tech, but incredibly impractical.	1
I believe if sensitivity is altered to the operator, the Android controller could be very effective.	1

<b><u>Comments</u></b>	<b><u>No. of Responses</u></b>
Very touchy, which leads to problems when precision is needed.	1
Too sensitive. Not recommended for use in combat zone.	1
I thought the joystick control was a little too sensitive.	1
Perhaps being able to view the phone horizontally instead of vertically and/or using a stylus might make control easier.	1
Too difficult to control speed as well as turns.	1
At times hard to maneuver when I wanted it too.	1
Difficult to make minor course corrections.	1
Exit and menu buttons should be smaller when using the steering button.	1
The absence of buttons made it a lot harder to control.	1
Ran into signal connection errors as well.	1
Would rather use on obstacles where I would have more room to maneuver.	1

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## **Appendix D. End of Experiment**

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This appendix appears in its original form, without editorial change.

**SAMPLE SIZE = 30**

1. Which controller did you prefer overall?

<b>Number of Responses</b>		
<b>Xbox Controller</b>	<b>Android Controller</b>	<b>No Preference</b>
26	2	2

**Comments**

**No. of Responses**

**Xbox**

Xbox easier to use.	7
Just works better.	1
Easier to operate.	1
There was something physical to hold while steering.	1
Easy to control/manipulate.	5
Xbox make operating robot a simple task.	2
More maneuverability.	1
Reacts instantly to your actions.	1
More tangible.	2
More natural.	2
A lot smoother.	1
Did not require multiple inputs to function properly.	1
Joystick was natural to use; made the difference.	3
Easier to control speed, direction, and movement.	7
Turning was clearer.	1
Felt more accurate outcome of intended movements.	1
More responsive and less room for error.	1
Has great sensitivity.	2
Even with the backpack, it was significantly easier than the Android.	1
Am used to this, like when playing games.	1
Familiar with remote for Xbox.	1
Only negative is the equipment and cords you had to carry.	1

**No preference**

Android worked better outdoors, I believe, when you kept constant pressure on the touch screen.	1
I would rather use the Android on outside obstacles where I would have more room to maneuver and use the Xbox in more restricted areas.	1

2. Do you have any suggestions for ways to increase the effectiveness of the **Xbox Controller**?

<u>Comments</u>	<u>No. of Responses</u>
Really effective.	1
For outside, find a way to make it all together with screen.	1
Find some way to mount the phone onto the controller.	1
Attach screen to the remote.	3
Integrate screen into controller to keep from having to carry two devices along with the weapon.	2
Get the screen attached somehow or make computer in bag be the monitor as well.	1
If it could have a screen attached to it, as opposed to using the phone as the screen, it would make maneuvering a lot better.	1
Less cords. Can you do wireless?	1
Redesign with only features used for movement of robot and also add a screen.	1
Larger viewing screen (Droid x 4.3" screen).	1
Speed control.	1
Eliminate extraneous buttons and shrink size of controller.	2
Make the buttons/joystick a little larger could make easier.	1
Use a joystick with different buttons place on top of it.	1
Use both joysticks, one for steering and one for acceleration.	1
Xbox should be autonomous.	1
Work on stationary turning.	1
Definitely use both joysticks. One for the left track and one for the right.	2
Maybe would be easier to operate with the use of both toggles. Left toggle-directional, right, forward and back (throttle).	1
Turning buttons left and right for top of controller.	1
Find a way to place flipper buttons where my fingers won't touch them (control design). Do you need a button (green one) to enable joystick to work?	1
In a field environment it might be easier if the controller and screen could be attached to one another.	1
Smaller pack for the back.	1
Make it a one-handed device so we can ditch the backpack.	1
Losing the backpack would be a plus, but not a must to affect performance.	1

3. Do you have any suggestions for ways to increase the effectiveness of the **Android Controller**?

<u>Comments</u>	<u>No. of Responses</u>
Is good, it just requires more practice.	1
It's impractical and the screen isn't uniformly sensitive.	1
Include a stylus.	1
Very frustrating user interface.	1

<b><u>Comments</u></b>	<b><u>No. of Responses</u></b>
Needs to be more responsive. Too much delay when turning and driving at the same time.	1
Fine tune the toggle screen or have real buttons.	1
Bigger touch screen.	5
Increase the area where the finger has control over the steering. With such a small area, those of us with large fingers had a harder time steering.	1
Make the controls bigger.	1
Make buttons (exit, menu) smaller so they aren't accidentally activated when going left and right.	1
Larger buttons to maneuver. Rather crowded on screen. Worried about hitting flipper buttons when going left.	1
Less sensitivity.	7
Sensitivity needs to be better calibrated.	3
Probably be more effective if calibrated to operator.	1
Sensitivity of the controller needs to be better. Sometimes when using, I had difficulties controlling the robot effectively.	1
Decrease the sensitivity of the tracking of the track pad.	1
Controls were much too sensitive with too little difference in finger position between barely moving and full speed.	1
Make it not so touchy and jumpy. I did better when I maintained contact with screen at all times.	1
More range of motion for control of movements.	1
Regulate speed.	2
Adjust left and right mounts.	1
Turning needs to be perfected; hard to control.	2
Make the digital joystick larger because if you moved your finger too far over you would lose controls.	1
Don't use them.	2

4. Which controller did you prefer when performing the following tasks?

	<b>No. of Responses</b>	
	<b>Xbox</b>	<b>Android</b>
Navigating around obstacle	30	0
Driving straight along course (s)	27	3
Driving through a turn	28	2
Manning the robot using bounding technique	19	11
Maneuvering the robot through the building	29	1
Negotiating the robot through confined areas	30	0

5. When considering the advantages and disadvantages of a one-handed vs. two-handed operation, which do you prefer and why?

Number of Responses			
One-handed	Two-handed	Both	NR
9	19	1	1

<u>Comments</u>	<u>No. of Responses</u>
<b><u>One-handed</u></b>	
Is better in combat or a high stress situation because you have a free hand to do other things.	1
It frees my other hand to use the radio, if necessary, or to carry my weapon, etc.	3
Android is easier to use one-handed since the screen is on the controller.	1
Allows me to access my weapon more easily.	1
Can keep hidden better.	1
More convenient.	1
Better when fired upon.	1
Would allow for quicker recovery of firearm or to open doors, etc.	1
Easier mobility, especially with a full combat load.	1
Cumbersome to carry weapon pack and controller.	1
With practice one hand is better.	1
Hard to control multi-directional.	1
Second hand can be on my rifle for easier transition in battle.	1
Rifle must be readily available in combat zone.	1
<b><u>Two-handed</u></b>	
Familiarity with the Xbox makes it easier.	1
Xbox is easiest to use by far.	1
Allowed more control.	9
Allows for more options.	1
I feel people would be more confident when using the Xbox controller.	1
Easier with movements.	2
Allows more positive control over steering method, keeps a steady screen and, therefore, better steering.	1
More control. If I am maneuvering something in combat like this, I will still be consumed whether it be one or two-handed.	1
Gave you something to hold on to for more stability.	2
Felt more confident.	1
More support means more control and more fine touch.	1
Stability to operate control. If controller was attached to equipment, then might be able to do one-handed.	1
You maintain a better control over body motion and controller. Breathing and more fluid movements with controller are better maintained.	1
You have the ability to trigger multiple options at the same time as well as a more stable controller/screen.	1
As long as you have a buddy holding a weapon is not a problem, and with	1

<u>Comments</u>	<u>No. of Responses</u>
two hands you are better able to control/space controls than a small compact one-handed system.	
Pressure depends on two hands.	1
Helps with changing direction.	1
Helps do different tasks to increase mobility.	1
You don't have hand free for weapon or if you need it.	1
Android is autonomous.	1

6. Using the scale below, rate your thoughts on the importance of having one hand free.

1	2	3	4	5	6	7
Don't need at all	Could do without	Not important	Neutral	Important	Very important	Extremely important

MEAN RESPONSE
4.47

<u>Comments</u>	<u>No. of Responses</u>
You have a weapon and need to be able to shoot it.	1
Two hands mean someone would be dedicated to the robot. Security could be an issue.	1
Great test. Just need to find a way to have Xbox controller complete with display.	1
Whether using one or two hands, controller would still have to be put down or away before using weapon. Ideally, weapon use for the person controlling the robot would be minimal.	1
One hand free is not important. I will still need to drop the controller in one-handed situations to return fire.	1
If you incorporate this into your SOPs and or combat drills, you will learn how to manipulate this system while using your primary and secondary weapon.	1
In the field, it is always important to be able to fire your weapon, move and be aware of the situation at all times. When moving the robot, you tend to focus on the act alone and things around you become less acknowledgeable. Have one hand free would be great, but 2 hands without cords would help maintain more control.	1
I would have to test in more realistic battlefield environments before I could give an educated answer as to whether it would be important to have a hand free during testing. At this point, I feel that the increased control over steering with two hands outweighs the importance of having one hand free.	1
It would probably be more convenient but I felt better control with two hands.	1
Takes a lot of concentration to use vehicle with all the devices. One hand free is not going to help you fire upon the enemy while in use. Maximize the efficiency and effectiveness of the device, whether it requires one	1

<b><u>Comments</u></b>	<b><u>No. of Responses</u></b>
hand or two. You are not likely to be fighting and controlling the Android at the same time. You will probably be behind cover controlling it, meaning you can use two hands.	1
Though having a free hand would be good, your eyes would still be on the screen.	1

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## List of Symbols, Abbreviations, and Acronyms

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ARL	U.S. Army Research Laboratory
CISD	Computational and Information Sciences Directorate
HRED	Human Research and Engineering Directorate
LADAR	laser detection and ranging
NASA-TLX	National Aeronautics and Space Administration-Task Load Index
OCS	Officer Candidate School
OCU	operator control unit
PDA	personal digital assistant
TOC	tactical operations center

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